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Investigation of the Performance of Residential Electronic Filters in Actual Use

PROJECT OBJECTIVES

The main objective of the project was to determine how occupants of a house could easily check the proper operation of their electronic filter (for example, by monitoring the colour change of a white surface), or make recommendations regarding the number of times per year the collector plates and ionizing wires of an electronic filter need to be cleaned. A second objective was to investigate whether heart rate variability, an indicator of cardio-respiratory health in a non-resting subject, could be used to establish a link between occupant health and effective domestic air filtration.

METHODOLOGY

The project was initiated in September 2005 with a literature search, the planning of the measurements in cooperation with UQAM, and the recruitment of participant households. An intensive measurement period was conducted during December 2005, including the end-of-year holidays. In total, the particle concentrations in five houses, all having a central ventilation system with an electrostatic precipitator (electronic filter), were repeatedly measured with an optical laser particle counter, with each data series entailing measurements every 15 minutes over a typical 24-hour period. Twenty-three such data series were assembled between December 3, 2005 and January 4, 2006. The measurements included particle concentrations not just upstream and downstream of the filter, but also in the outside air and at least at one point in the house (the bedroom was used where possible). In each house, these measurements were taken both with the filter "as is", on arrival the first day of the test, and after cleaning, as foreseen in the initial work plan. The "filter performance", expressed as a percentage, was defined as the ratio of the counted number of particles between 0.5 and 5 microns that were blocked by the filter to the total number of such particles upstream of the filter.

In several cases, repairs, reinstallation of the filter, or an improvement in the ventilation system (sealing of the ducts upstream of the furnace fan and downstream of the filter) were necessary in order to reliably detect the improvement in filter performance after cleaning. The first data series in a given house thus typically included a minimum of three days of measurements. Subsequently, the deterioration in the performance of the filters was observed, either over the course of the days immediately following, or as part of a second data series collected after the test equipment had been removed and reinstalled.

In parallel with these measurements, the heart rate of one household occupant was measured during several hours of rest (the four or five hours following bedtime) and during the day whenever the occupant was at home.

ELECTRONIC FILTER RESULTS

The homeowners varied in their practices, ranging from those that scrupulously cleaned the filter cartridges with a mild detergent on a monthly basis throughout the year, to those that cleaned the filter only once or twice per year, to those that were not even aware that cleaning was necessary and had cleaned the pre-filter only once in a dozen years.

Similarly, electronic filter performance varied widely among the houses, both before and after cleaning, ranging from -400% (in one house that, while very well kept, had leaks between the garage and the room containing the furnace, and between the filter and the furnace intake fan) to 100% (performance of the measurement equipment was verified by removing the downstream sensor to establish that it was actually detecting particles).

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Air leaks in the ducts, between the filter and the furnace intake fan, which are at negative pressure, can eliminate the benefits of filtration entirely. In fact, these leaks can even be the principal point of entry for particles and pollutants into the inhabited zone of the house, regardless of the performance of the filter. This situation merits consideration given that the room containing the furnace can experience negative pressure and is often:

- a significant source of pollutants (due to the presence of fuel, exhaust ducts, stored chemical products, and so on);
- easily contaminated by other particle sources, such as an unsealed door leading to a garage, or a central vacuum cleaner, located in the room housing the furnace, and exhausting its air into the room. This is especially problematic given that central vacuum cleaners are often poorly filtered compared with portable vacuum cleaners, due to the former normally being designed to exhaust outside the house.

The best performing filter of the five houses removed 80% of the particles between 0.5 and 5 microns over 18 days of operation. It was neither the newest filter nor the filter with the least-oxidized appearance. After cleaning, however, its performance dropped to less than 60% and the house took on a strong "swimming pool" odour, characteristic of ozone. It was the only day (of the 23 data series) on which ozone was detected (by odour only). Following a second cleaning and verification that the cartridge was seated correctly, the filter performance was measured at 100%, which declined to approximately 90% after 48 hours of operation. The ozone generation problem was observed only in the case of the higher performing filter amongst the five studied.

Apart from the preceding observation, cartridge cleaning generally improved performance, with few exceptions. In these exceptional cases, poor electrical contact following the reinstallation of the cartridges is suspected. In the course of this investigation, such unpredictable contact problems were occasionally observed.

The industry provides mediocre service to its clients. After a reputable service centre made a $200 repair that involved replacing a defective high-voltage generator in one of the units, it was impossible to eliminate electrical contact problems or to obtain a performance better than 40%. The only "Electronic Air Cleaner Monitors" on the market are in reality simple timers that remind the homeowner to clean the cartridges every 15, 30, 45, or 60 days, according to a schedule judged appropriate by the installer. The recommended diagnostic of listening at an upstream duct for the crackling noise characteristic of electrostatic discharge seems unreliable: in this study, it was possible to hear this sound emanating from a filter, having a leak in the fan duct, with a performance lower than 15%.

The most important observation of this investigation was that the decline in electronic filter performance following cleaning is much more rapid than anticipated. A typical case is that of House 2. The performance varied between 15 and 40% over two weeks to one month of use, and jumped to above 60% after cleaning. Having seen filter performance fall to as low as 15% within only 10 days of cleaning, the performance of the filter in House 2 was monitored in the days immediately following cleaning.

Performance was seen to decline from 75% to 35% within 48 hours (*see* figure for House 2, 48 hours after cleaning).

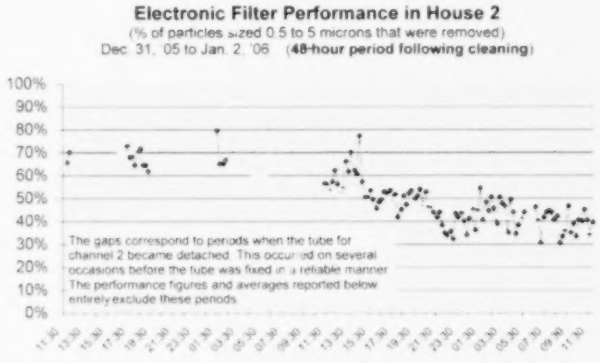
Electronic Filter Performance in House 2
(% of particles sized 0.5 to 5 microns that were removed)
Dec. 31, '05 to Jan. 2, '06 (48-hour period following cleaning)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
The gaps correspond to periods when the tube for channel 2 became detached. This occurred on several occasions before the tube was fixed in a reliable manner. The performance figures and averages reported below entirely exclude these periods.

Figure 1 Degradation of filter performance in House 2

In another house, performance fell by 5 percentage points (from 60%) within a single day of cleaning (*see* figure for House 6, first day after cleaning).

This rapid deterioration in performance eliminates the possibility of simple diagnostics, such as the fouling of a white surface, meant to permit the occupants of a household to determine the state of their filter.

Researchers checked the performance of the pre-filter when the electronic filter was turned off. It was verified that the poor levels of performance at which the electronic filters would stabilize were not an indication that only the prefilter was functioning. This was done in House 2 only, on the last day of measurements. The electrostatic precipitator cartridges still had an impact: filter performance was about 5% with only the prefilter, but around 40% with the filter on (48 hours after cleaning).

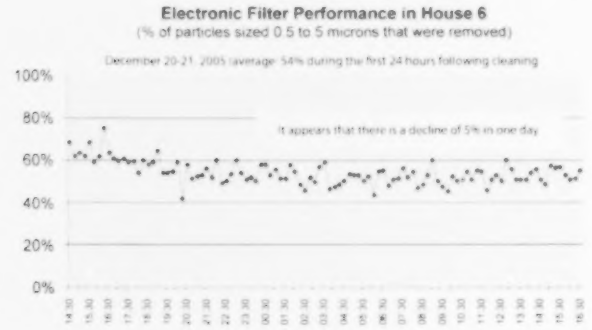
Electronic Filter Performance in House 6
(% of particles sized 0.5 to 5 microns that were removed)
December 20-21, 2005 (average: 54% during the first 24 hours following cleaning
100%
80%
60%
40%
20%
0%
It appears that there is a decline of 5% in one day

Figure 2 Degradation of filter performance in House 6

RESULTS OF INVESTIGATION OF HEART RATE VARIABILITY (HRV)

Concerning the link between heart rate variability and $PM_{2.5}$, it is not possible to draw conclusions from this study since the subjects were too few (5) and too dissimilar in age, state-of-health, and so on. In addition, the level of $PM_{2.5}$ in the indoor air of the houses studied (typically < 5 µg/m³) was below the lowest levels in other studies of HRV (typically > 20 µg/m³) and was generally quite stable, which meant that the subjects were not exposed to large variations in $PM_{2.5}$.

This investigation identified several studies that showed a link between HRV and $PM_{2.5}$, namely, that HRV was diminished with higher $PM_{2.5}$, even within the period of a day. In other words, this indicates that the body reacts quickly to increases in $PM_{2.5}$ and higher $PM_{2.5}$ levels negatively impact cardio-respiratory health. The few anecdotal observations possible in this investigation tend to support the findings of the studies found in the literature search.

CONCLUSIONS

To improve performance of electronic filters, homeowners should:

1. Verify that the ducts and connections between the filter and the entrance to the furnace are airtight. Listen to the ventilation system: no whistling or suction sound should be heard. This advice also applies to other types of filters.

2. Eliminate potential sources of contamination from the mechanical room. Exhaust the air from the central vacuum cleaner to the outside. Ensure that the door between the garage and the room housing the furnace seals tightly. Clean the electronic filter, following the manufacturer's instructions, as often as possible—even weekly. Make sure that the cartridges are properly seated in place. Be vigilant for "swimming pool odours" indicating that the filter is producing ozone, a gas that irritates the respiratory tract. If this odour is detected, clean the filter again, let it dry completely, and put it back in place. If the odour persists, contact a service centre.

3. Install a fibre filter downstream of the electronic filter. This will ensure a certain minimum level of performance in case of filter malfunction. The filter should remain clean; soiling indicates that the electronic filter is functioning poorly!

4. To show that domestic air filtering can be associated with improvements in the cardio-respiratory health of the occupants, further HRV investigations measured during the sleeping hours of the occupants seems to be an interesting research avenue. The research would have to be conducted with a larger sample of more homogeneous subjects (between 30 and 50 years old, without heart problems) over a longer period of time. This would allow occupants to be exposed to larger variations of particles, to measure the effect of filtration systems that run at their optimal performance (which was not the case for the electronic filters examined here) and to use more comfortable and reliable heart rate monitors.

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